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US 4862184 A

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(54) Dielectric-loaded antenna

(57) A dielectric-loaded antenna for operation at frequencies over 200 MHz has a cylindrical ceramic core (12) with a relative dielectric constant greater than 5. The core (12) is formed with recesses in its cylindrical outer surface and the recesses are filled with conductive material thereby forming a three-dimensional antenna element structure having antenna elements (10A - 10D) inlaid in the ceramic material and with their outer surfaces flush with the outer surface of the core. The antenna is manufactured by forming the core from the ceramic material when in a green state, firing the core, metallising the core outer surface whereby conductive material enters the recesses as well as covering other parts of the core outer surface, and then machining the metallised core to an extent such that conductive material is left in the recesses but portions of the core between the recesses are exposed. The recesses are generally rectangular in cross-section such that the conductive antenna elements (10A - 10D) have well-defined edges of a predetermined thickness to provide low electrical resistance along the element sides where radio frequency currents are concentrated.

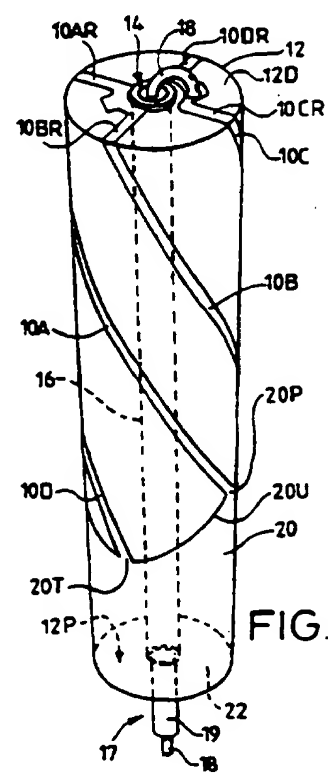

FIG.1.

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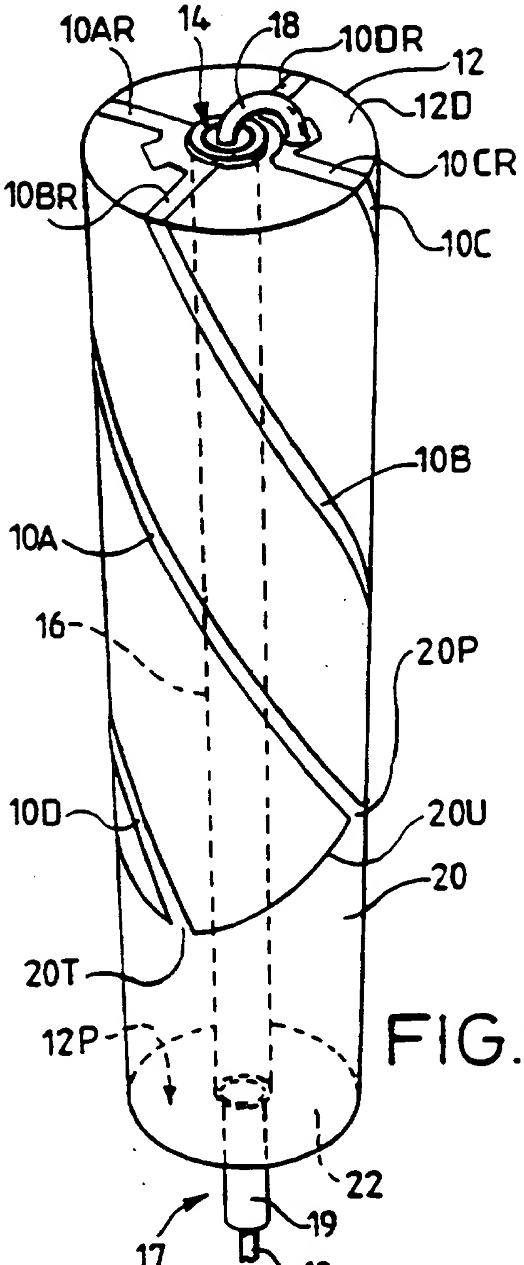

FIG.1.

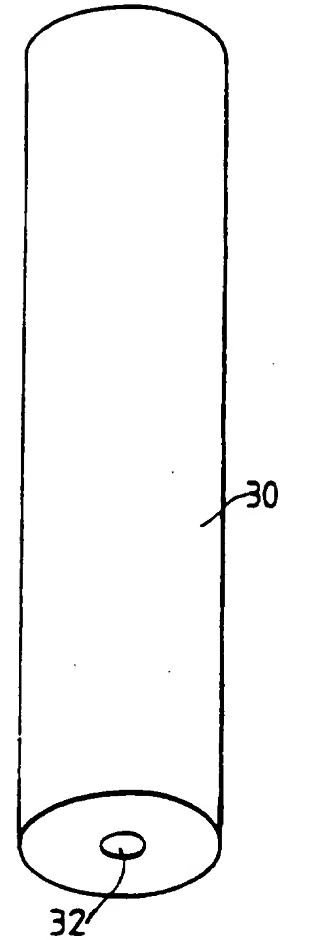

FIG.2.

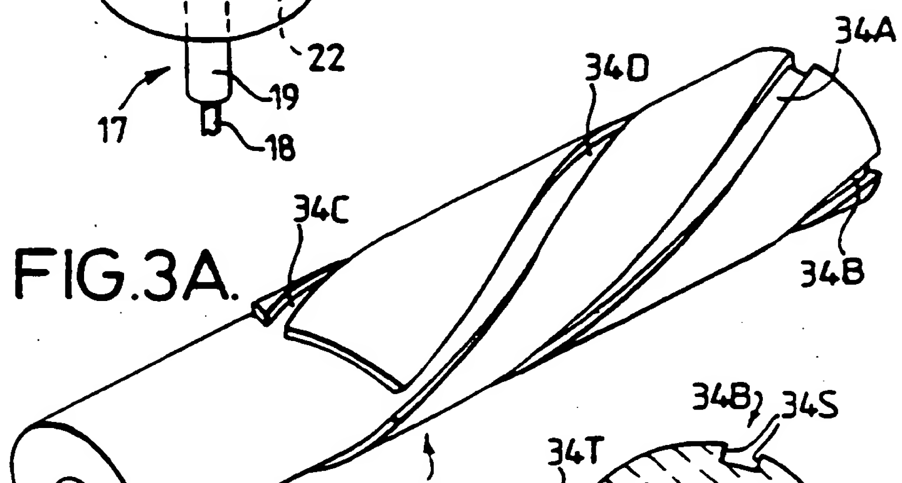

FIG.3A.

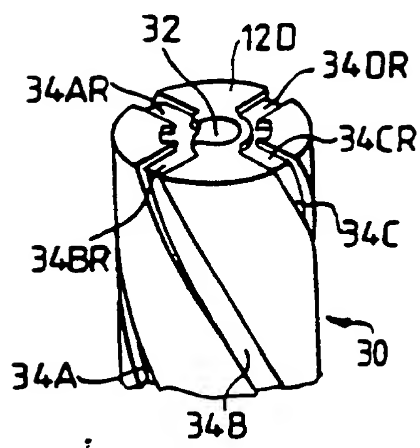

FIG.3B.

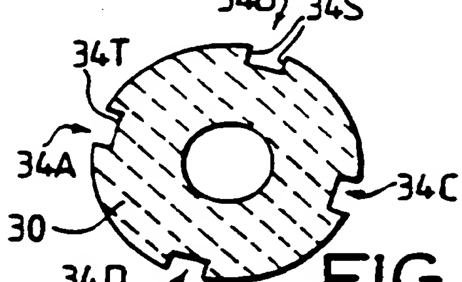

FIG.3C.

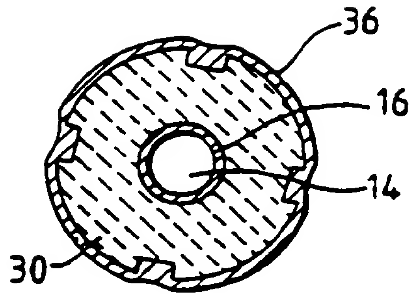

FIG.4.

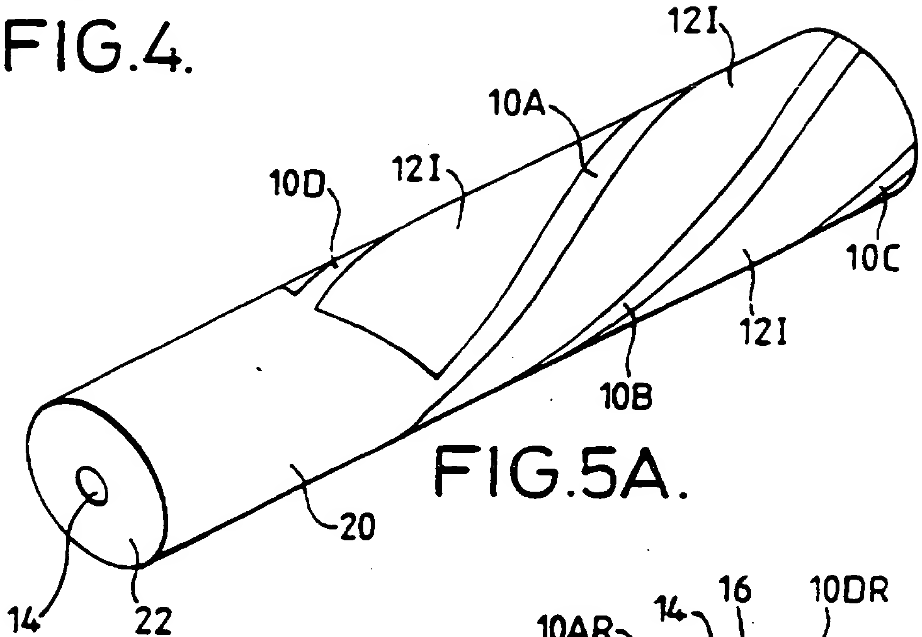

FIG.5A.

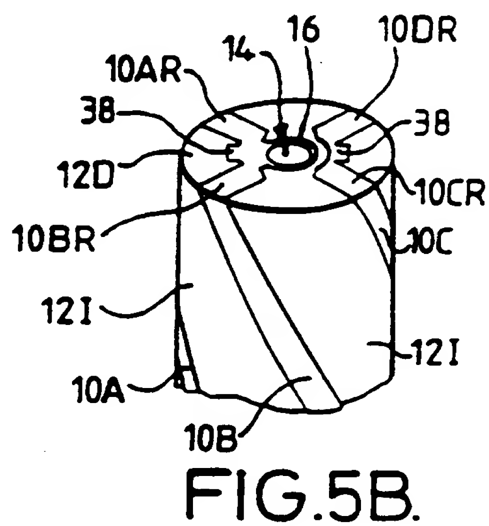

FIG.5B.

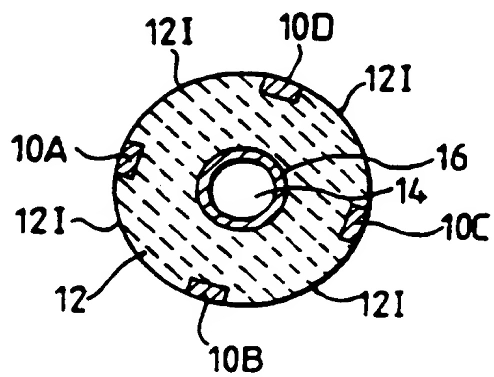

FIG.5C.

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DIELECTRIC-LOADED ANTENNA

This invention relates to an antenna for operation at frequencies in excess of 200 MHz, the antenna comprising an electrically insulative core and a three-dimensional antenna element structure disposed on the outer surface of the core. The invention also relates to a method of manufacturing an antenna.

Such an antenna is disclosed in British Published Patent Application No. 2292638A, the disclosure of which is incorporated in the present application by way of reference. Application No. 2292638A discloses a quadrifilar antenna having two pairs of diametrically opposed generally helical antenna elements disposed on a cylindrical ceramic core. At one end of the core, the antenna elements are connected to a coaxial feeder structure extending axially through the core. Extending over the core from the other end there is a conductive sleeve the rim of which acts as a common linking conductor for the helical antenna elements whereby the sleeve operates as a trap to isolate the elements from an antenna ground connection when the antenna operates in a balanced mode with circularly polarised signals.

The prior antenna is particularly suitable for receiving L-band global positioning system (GPS) signals at 1575 MHz, at which frequency the antenna core diameter is typically 5mm. The length of the core may be three or more times its diameter and the width of the antenna elements may be about 0.3mm. These dimensions are small compared with the dimensions of air-cored helical antennas due to the loading of the ceramic dielectric which may typically have a relative dielectric constant of ϵ_r equal to 36 or more. This small size of the antenna, while bringing advantages in terms of compactness and robustness, creates difficulties in terms of applying conductive material to sufficiently close tolerances. The problem is aggravated by the need to apply the material to a solid body rather than to a simple planar surface.

Related antennas which present similar difficulties are disclosed in co-pending British Patent Application No. 9610581.2 and British Patent Application No. 9603914.4. The

disclosure of these applications is incorporated in the present application by way of reference.

It is an object of the present invention to provide an antenna in which the antenna elements and their relative locations are defined to close tolerances, and which is susceptible to high volume manufacture. It is also an object of this invention to be able to manufacture antennas on a high yield basis and having a consistent electrical performance.

In accordance with one of its aspects, the invention provides an antenna for operation at frequencies in excess of 200 MHz, comprising an electrically insulative antenna core of a material having a relative dielectric constant greater than 5, a three-dimensional antenna element structure disposed on the outer surface of the core and defining an interior volume, and a feeder structure which is connected to the antenna element structure and passes through the core, the material of the core occupying the major part of the interior volume, wherein at least part of the antenna element structure is disposed in recesses in the core. Preferably, the recesses comprise a plurality of channels with the antenna element structure having a plurality of elongate conductive antenna elements housed in the channels, the side walls of the channels defining the lateral extent of the antenna elements.

According to another of its aspects, the invention provides an antenna in which the core is formed with a plurality of channels and the elements are housed in the channels so as substantially to fill the channels whereby the conductive material in the channels is flush with the outer surface of those portions of the core which are exposed between the channels.

In a preferred embodiment of the invention, the core is cylindrical, and the antenna elements are helical conductors arranged on the outer cylindrical surface of the core generally coextensively in the axial direction. In the preferred antenna, one of the recesses in the core is an annular region of reduced diameter supporting an annular conductive

sleeve, the rim of which forms a common linking conductor linking the ends of the helical elements. The helical elements, the sleeve, and the portions of the outer surface of the core exposed between the helical elements together form a substantially uniform cylindrical outer surface of the antenna.

In accordance with a third aspect of the invention, the antenna is produced by forming an electrically insulative antenna core from a material having a relative dielectric constant greater than 5, the core comprising a body of the material with recesses formed in the outer surface. The core outer surface is then metallised during which operation conductive material enters the recesses as well as covering other parts of the outer surface of the core. Next, material is removed from the metallised core to an extent which leaves the conductive material in the recesses but exposes portions of the core between the recesses, thereby to form a three-dimensional antenna element structure on the core. Such a structure defines an interior volume, the major part of which is occupied by the material of the core.

Advantageously, the material of the core is a ceramic material and the step of forming a body of such material includes shaping the material in an initial unfired, green state in which it is relatively soft and then firing the shaped material into a hard sintered state prior to the metallisation step. The recesses are preferably formed while the material is in its green state, either by moulding, e.g. by injection moulding, or by extruding a rod of the green state material and then cutting the recesses using, for instance, a four-axis milling machine.

Metallisation may be performed by dipping the core in a colloid comprising a liquid suspension of metallic particles and then firing the dipped core to leave a solid conductive coating, and the material removing step may be performed by machining the metallised core to form a uniform cylindrical surface with portions of the ceramic core exposed. Such material removal may conveniently be performed by centreless grinding.

The invention allows an antenna element structure to be built on a solid dielectric core such that the edges of conductive antenna elements are well-defined and of a predetermined thickness. This assists in the production of antennas to close tolerances and in avoiding unwanted reductions in edge thickness which can significantly affect the resistance of the elements at high frequencies, given that at the typical operating frequencies of the antenna current tends to be concentrated at the edges.

The invention will now be described by way of example with reference to the drawings in which:

Figure 1 is a perspective view of an antenna in accordance with the invention, viewed from above and one side;

Figure 2 is a perspective view of an extruded ceramic rod from which the antenna of Figure 1 is manufactured;

Figures 3A, 3B, and 3C are respectively a first perspective view of the antenna core viewed from one end and to one side, a fragmentary second perspective view of the antenna core viewed from the upper end and to one side, and a transverse cross-section of the core;

Figure 4 is a transverse cross-section of the antenna core following metallisation; and

Figures 5A, 5B, and 5C are respectively a first perspective view of the antenna prior to insertion of a feeder structure, viewed from a lower end and one side, a fragmentary second perspective view of the antenna viewed from an upper end and one side, and a transverse cross-section of the antenna.

Referring to Figure 1, a dielectric-loaded antenna in accordance with the invention has an antenna element structure with four longitudinally extending antenna elements 10A, 10B, 10C, and 10D formed as metallic conductors inlaid on the cylindrical outer surface of a

ceramic core 12. The core has an axial passage 14 with an inner metallic lining 16, and the passage houses a feeder structure in the form of a coaxial cable 17 having an inner conductor 18 and an outer shield 19. Shield 19 is electrically connected to metallic lining 16 by an intermediate solder layer (not shown). The feeder structure so formed allows a feed line to be connected to the antenna elements 10A - 10D.

The antenna element structure also includes corresponding radial antenna elements 10AR, 10BR, 10CR, and 10DR formed as metallic conductors inlaid in a distal end face 12D of the core 12 and connecting ends of the respective longitudinally extending elements 10A - 10D to the feeder structure. The other ends of the antenna elements 10A - 10D are connected to a common virtual ground conductor 20 in the form of a metallic sleeve surrounding a proximal end portion of the core 12. This sleeve 20 is in turn connected to the lining 16 of axial passage 14 by a metallic layer 22 on the proximal end face 12P of the core 12.

The four longitudinally extending elements 10A - 10D are of different lengths, two of the elements 10B, 10D being longer than the other two 10A, 10C by virtue of extending nearer the proximal end of the core 12. At any given axial position, the elements of each pair 10A, 10C; 10B, 10D are diametrically opposite each other on opposite sides of the core axis.

Each of the elements 10A -10D follows a simple helical path, but since each subtends the same angle of rotation at the core axis, in this case 180° or a half turn, the screw pitch of the long elements 10B, 10D is steeper than that of the short elements 10A, 10C. The upper linking edge 20U of the sleeve 20 is of varying height (i.e. varying distance from the proximal end face 12P) to provide points of connection for the long and short elements respectively. Thus, in this embodiment, the linking edge 20U follows a zig-zag path around the core 12, having two peaks 20P and two troughs 20T (only one of each is shown in Figure 1) where it meets the short elements 10A, 10C and long elements 10B, 10D respectively.

Each pair of longitudinally extending and corresponding radial elements (for example 10A, 10AR) constitutes a conductor having a predetermined electrical length. In this embodiment, it is arranged that the total length of each of the shorter element pairs 10A, 10AR; 10C, 10CR has a transmission delay of about 135° at the operating length, while the longer element pairs 10B, 10BR; 10D, 10DR produce a longer delay of about 225°. Thus, the average transmission delay is 180°, equivalent to an electrical length of $\lambda/2$ at the operating wavelength. The differing lengths produce the required phase shift conditions for a quadrifilar helix antenna for circularly polarised signals specified in Kilgus, "Resonant Quadrifilar Helix Design", The Microwave Journal, Dec. 1970, pages 49-54.

Two of the element pairs 10C, 10CR; 10D, 10DR (i.e. one long element pair and one short element pair) are connected at the inner ends of the radial elements 10CR, 10DR to the inner conductor 18 of the feeder structure at the distal end of the core 12, while the radial elements of the other two element pairs 10A, 10AR; 10B, 10BR are connected to the feeder screen formed by the combination of metallic lining 16 and shield 19. At the distal end of the feeder structure, the signals present on the inner conductor 18 and the feeder screen are approximately balanced so that the antenna elements are connected to an approximately balanced source or load.

With longitudinally extending elements 10A - 10D having a left-handed sense as shown in Figure 1, the antenna has its highest gain for right-hand circularly polarised signals. If the antenna is to be used instead for left-hand circularly polarised signals, the direction of the helices is reversed and the pattern of connection of the radial elements is rotated through 90°. In the case of an antenna suitable for receiving both left-hand and right-hand circularly polarised signals, the longitudinally extending elements can be arranged to follow paths which are generally parallel to the axis.

The conductive sleeve 20 covers a proximal portion of the antenna core 12, thereby surrounding the feeder structure 16 -19, with the material of the core 12 filling the whole of the space between the sleeve 20 and the metallic lining 16 of the axial passage 14.

Since the sleeve 20 forms a cylinder which is connected to the lining 16 by a metallic layer 22 on the proximal end face 12P of the core 12, the combination of the sleeve 20 and layer 22 forms a balun so that signals in the transmission line formed by the feeder structure are converted between an unbalanced state at the proximal end of the antenna and an approximately balanced state at an axial position generally at the same distance from the proximal end as the upper linking edge 20U of the sleeve 20. Due to the core material of the antenna having a foreshortening effect, and the annular volume between the inner conductor 18 and the shield 19 being filled with an insulating dielectric material having a relatively small dielectric constant, the feeder structure distally of the sleeve 20 has a short electrical length. Consequently, signals at the distal end of the feeder structure are at least approximately balanced.

An annular path exists along the linking edge 20U for currents between the elements 10A-10D, effectively forming two loops, the first with short elements 10A, 10C and the second with the long elements 10B, 10D. The edge 20U is effectively isolated from the ground connection formed by its proximal edge due to the approximate quarter wavelength trap produced by the sleeve 20.

The antenna has a main resonant frequency of 500 MHz or greater, the resonant frequency being determined by the effective electrical lengths of the antenna elements and, to a lesser degree, by their width. The length of the element, for a given frequency of resonance, are also dependent on the relative dielectric constant of the core material, the dimensions of the antenna being substantially reduced with respect to an air-cored similarly constructed antenna.

The preferred material for the core 12 is zirconium-tin-titanate-based material. This material has a relative dielectric constant of 36 and is noted also for its dimensional and electrical stability with varying temperature. Dielectric loss is negligible. With this relative dielectric constant, an antenna as described above for L-band GPS reception at 1575 MHz typically has a core diameter of about 5mm and the longitudinally extending elements 10A - 10D have an average longitudinal extent (i.e. parallel to the central axis)

of about 16mm. The longer elements 10B - 10D are about 1.5mm longer than the shorter elements 10A - 10C. The width and depth of the elements 10A - 10D are typically 0.75mm and 0.3mm respectively. At 1575 MHz, the length of the sleeve 22 is typically in the region of 8mm. Dimensions of the antenna elements 10A - 10D can be initially estimated from guide velocity of propagation measurements in helical transmission line medium using eigen-delay calibration techniques. Precise dimensions can then be determined by trial and error iteration until the required phase difference is obtained.

The preferred method of manufacture will now be described with reference to the other figures of the drawings.

A first manufacturing first stage comprises extruding a rod 30 of ceramic material, the rod being of circular cross-section and having an axial passage 32, the diameter of which is no greater than one half of the diameter of the rod, as shown in Figure 2. The rod 30 is extruded from a batch of green ceramic material comprising the combination of a ceramic powder mixed with a binder.

A second manufacturing stage results in a component as shown in Figures 3A to 3B. While the extruded rod 30 is still in the green state, it is machined using a milling machine capable of at least four-axis operation to form channels 34A, 34B, 34C and 34D of helical form. These channels 34A - 34D are of rectangular or square section, having longitudinal sides 34S and a substantially flat base 34T (see Figure 3C). The sides 34S meet the outer cylindrical surface of the rod with an angle of intercept of a little less than 90°, the exact angle at the channel edge depending on the width of the channel as a proportion of the rod diameter. Angles in the range of from 45° to 90° are preferred. The rectangular channel cross-section is achieved by fitting the milling machine with a square-ended cutter which is controlled so as to be oriented always towards the central axis of the rod 30 (i.e. perpendicularly to the outer surface of the rod 30 at any given cutting location).

In addition to forming channels 34A - 34D, the milling machine is used to reduce the diameter of a proximal end portion 30P of the rod 30, as shown in Figure 3A, to produce

an annular region of reduced diameter. This annular region extends from the proximal end face 12P to meet the ends of channels 34A - 34D, the depth of cutting of the reduced diameter portion being the same as the cutting depth used to form channels 34A - 34D.

This stage of the method further includes forming radial channels 34AR, 34BR, 34CR, and 34DR in the distal end face 12D of the rod 30 as shown in Figure 3B, these radial channels being in registry with the distal ends of the helical channels 34A - 34D. Two of the channels 34AR, 34BR are formed so as to extend into the axial bore, whilst the other two radial channels 34CR, 34DR stop short of bore 32. Between these respective pairs of radial channels, further recess portions are cut to link them (and eventually to form soldering pads).

Depending on the characteristics of the ceramic material, the dimensions of the arrangement of channels, the portion of reduced diameter, and the length of the rod itself are all somewhat greater than in the finished product to allow for shrinkage during firing.

In this preferred method, then, once the above-described machined features have been produced, the rod 30 is fired in a kiln to form a rigid sintered state article of the required shape and dimensions.

Referring to Figure 4, the fired rod 30 is next metallised by immersing it in a metallic colloid which is a suspension of metallic power in an organic liquid, resulting in a metallic coating 36 being applied over the whole of the rod. This metallisation step includes filling the channels 34A - 34D and 34AR - 34DR with the metallic material so that the material extends between the side walls 34S (Figure 3C) of each channel up to the intersection of the side walls with the outer surface of the rod. In order to achieve the required depth in the recesses formed by the channels 34A - 34D and 34AR - 34DR, it may be necessary to repeat the dipping process, each dipping process being followed by a heating step to remove the organic liquid component of the colloid. At this stage the bore 32 is also metallised as shown in Figure 4 to yield passage 14 with metallised lining 16.

To form the antenna elements 10A - 10D, 10AR -10DR, and the conductive sleeve 20 of the finished antenna shown in Figure 1, the conductive coating is removed from those portions of the rod outer surface between the channels 34A - 34D, 34AR - 34DR and the rod portion 30P of reduced diameter. This is achieved in the preferred method by a centreless grinding technique whereby the complete outer cylindrical surface of the metallised rod is ground to a predetermined diameter sufficiently small to remove the metallisation layer 36 between the channels 34A - 34D and, preferably, to remove a thin outer layer of the rod 30 in these regions. The resulting article, as shown in Figure 5A, is a cylinder with a continuous cylindrical outer surface formed by the helical elements 10A - 10D, the conductive sleeve 20, and the islands 12I formed by the ground outer surface of the ceramic core between the helical elements 10A - 10D , as shown in Figures 5A - 5C.

The distal end face of the metallised rod 30 is also ground, in this case to form a continuous plane in which the radial elements 10AR - 10DR formed by metallisation in the radial channels 34AR - 34DR are flush with the adjacent surface of the core 12.

It will be noted that the arrangement of the channels 34AR - 34DR described above yields connections between the helical elements 10A, 10B and the metallic lining 16 of the axial passage 14, while helical elements 10C, 10D, although connected together, are insulated from lining 16. Small solder pads 38 are formed on the distal end surface 12D (see Figure 5B).

In some circumstances the finished article may not be perfectly cylindrical in that the helical elements 10A to D are dimpled, i.e. along the centre-lines of elements the height of the metallisation is less than at the sides. Thus, in this instance, only the peripheral edges of the elements 10A - 10D are flush with the outer surface of the ceramic core. Similarly the conductive sleeve 20 may reach the full diameter of the core only adjacent its distal edge 20U, and the radical elements 10AR - 10DR may be dimpled in the same way as the helical elements 10A - 10D.

The final stage is insertion of a semi-rigid coaxial cable 17 in the bore 14, as shown in Figure 1. This stage includes flowing solder by capillary action between the metal shield 19 of the cable and the metallic lining 16 of passage 14 to connect the cable preferably throughout its length, but at least at the two ends of the passage, and the soldering of the inner conductor 18 of the cable to the solder pad 38 associated with two of the radial conductors 10CR, 10DR.

Alternative methods of manufacture include forming the rod 30 shown in Figure 2 as a log using a pressing process (preferably an isostatic process) and then cutting channels as described above with reference to Figures 3A to 3C while the ceramic material is still in the green state.

Yet a further alternative method is to form the rod 30, including channels 34A - 34D, 34AR - 34DR and the rod portion 30P of reduced diameter, in a single moulding process, particularly an injection moulding process. In this case, the ceramic material initially takes the form of a slurry of appropriate fluidity for injection moulding. This requires a relatively high proportion of organic binder to be present in the slurry mix compared with the composition for extrusion or iso-static pressing, and the dimensional compensation for shrinkage must be adjusted appropriately. The degree of compensation for shrinkage may be estimated using a batch testing process in which a sample of each new ceramic material batch is first fired and the shrinkage measured. Then, based on the outcome of the sample test, one of a range of scaled dimension automatic mould tools is selected to accommodate the measured level of shrinkage. Once moulded, the parts are kiln-fired, metallised, and ground, as described above.

For low volume production, the milling stage of the first above-described process is omitted, and the rod is first kiln-fired in the configuration shown in Figure 2. This hard-fired ceramic material is then machined into shape using precision diamond-tipped tools and machine tools. Metallisation and grinding then proceeds as already described.

Another method of manufacture comprises: forming an undersized green-state dielectric rod and applying a layer of green-state ceramic material to the undersized rod in for example a rolling process. In this case the above mentioned recesses may be formed as apertures or recesses in the layer prior to application to the undersized rod. Subsequently the resulting composite body of ceramic material is fired and metallised as described above.

While the invention has been described in the context of a quadrifilar antenna for circularly polarised signals, it is to be understood that it has application in a variety of antennas within the scope of the claims, including the loop and twisted loop antennas disclosed in the above mentioned co-pending British Patent Application No. 9610581.2.

CLAIMS

1. An antenna for operation at frequencies in excess of 200 MHz, comprising an electrically insulative antenna core of a material having a relative dielectric constant greater than 5, a three-dimensional antenna element structure disposed on the outer surface of the core and defining an interior volume, and a feeder structure which is connected to the element structure and passes through the core, the material of the core occupying the major part of the interior volume, wherein at least part of the antenna element structure is disposed in recesses in the core.

2. An antenna according to claim 1, wherein the recesses comprise a plurality of channels formed in the outer surface of the core, and the antenna element structure comprises a plurality of elongate conductive antenna elements housed in respective said channels.

3. An antenna according to claim 2, wherein the channels each have sides which intersect portions of the outer surface of the core adjacent the respective sides with an angle of intercept in the range of from 45° to 90°, and wherein the corresponding antenna element extends from one said channel side to the other channel side, the antenna element being formed of a conductive material which fills the channel and has an outer surface flush with the adjacent outer surface portions.

4. An antenna according to claim 3, wherein the thickness T of the antenna element is given by $0.1W<T<W$, where W is the width of the elements.

5. An antenna according to claim 3 or claim 4, wherein the thickness of the antenna elements is at least 0.1mm.

6. An antenna according to any preceding claim, wherein the core is cylindrical and the antenna elements are helical and arranged in corresponding helical channels formed in the cylindrical outer surface of the core.

7. An antenna according to any of claims 1 to 5, wherein the core is a cylindrical body of ceramic material with an axial passage housing the feeder structure, the axial passage being of a diameter less than half of the outside diameter of the core, and wherein the antenna element structure comprises a plurality of interconnected elongate metallic antenna elements inlaid in the recesses between islands of exposed ceramic material, the inlaid elements and the islands forming a substantially continuous cylindrical surface over at least a portion of the antenna.

8. An antenna for operation at frequencies in excess of 200 MHz, comprising a cylindrical electrically insulative core of a material having a relative dielectric constant greater than 5, and a three-dimensional antenna element structure comprising a plurality of elongate generally helical conductive antenna elements arranged on the outer surface of the core generally coextensively in the axial direction, wherein the core is formed with a plurality of channels and the elements are housed in the channels so as substantially to fill the channels.

9. An antenna according to claim 8, further comprising:

an axial feeder structure passing through the core from a proximal end to a distal end thereof, respective ends of the helical antenna elements being coupled to the feeder structure in the region of the distal end of the core, and

a trap in the form of a conductive sleeve encircling part of the core proximally of the helical antenna elements and coupled to the feeder structure in the region of the proximal end of the core, the other respective ends of the helical antenna elements being coupled to a distal rim of the sleeve,

wherein the helical antenna elements, the sleeve and the portions of the outer surface of the core together constitute a substantially uniform cylindrical outer surface.

10. An antenna according to claim 9, wherein the helical antenna elements are coupled to the feeder structure by respective generally radial conductive elements housed in channels in a distal end face of the core.

11. An antenna according to claim 9 or claim 10, wherein the feeder structure comprises a coaxial transmission line in an axial bore through the core, the inner surface of the core being metallised to form a shielding conductor which is connected to at least one of the helical elements in the region of the core distal end and to the sleeve in the region of the core proximal end.

12. An antenna according to any of claims 8 to 11, wherein the channels are filled by the helical elements to the extent that the edges of the helical elements meet the outer edges of the channel sides, the radial thickness of the helical elements at the edges thereof being at least as great as their radial thickness at their helical centre lines.

13. An antenna according to any of claims 8 to 12, wherein each said helical element constitutes a half-turn winding centred on the axis of the core.

14. A method of manufacturing an antenna for operation at frequencies in excess of 200 MHz, wherein the method comprises the steps of:

forming an electrically insulative antenna core from a material having a relative dielectric constant greater than 5, the core comprising a body of the material with recesses formed in the outer surface;

metallising the core outer surface whereby conductive material enters the recesses as well as covering other parts of the core outer surface; and

removing material from the metallised core to an extent which leaves the conductive material in the recesses but exposes portions of the core between the recesses, thereby to form a three-dimensional antenna element structure on the core, the structure defining an interior volume the major part of which is occupied by the material of the core.

15. A method according to claim 14, wherein the step of removing material from the metallised core is performed by causing relative rotation between the core and a material removing tool to yield a cylindrical antenna in which the antenna element structure is disposed on a cylindrical outer surface of the antenna.

16. A method according to claim 15, wherein the material removing step is performed using centreless grinding of the metallised core.

17. A method according to claim 14, wherein the material removing step is performed by surface grinding.

18. A method according to claims 14 to 17, wherein the material of the core is a ceramic material and wherein the forming step includes shaping the material in an initial green state and then firing the shaped material into a sintered state prior to the metallisation step.

19. A method according to claim 18, wherein said shaping of the green material includes forming the recesses.

20. A method according to claim 19, wherein the shaping step comprises shaping the green material into a rod and cutting material from the rod to form the recesses.

21. A method according to claim 20, wherein the rod is generally cylindrical and the cutting step is performed using a milling machine capable of at least 4-axis operation.

22. A method according to claim 21, wherein the cutting is performed using a square-ended cutting tool oriented perpendicularly to the core outer surface.

23. A method according to any of claims 19 to 22, wherein said shaping is performed to produce an arrangement of the recesses the dimensions of which are greater than in the fired core to compensate for shrinkage during firing.

24. A method according to any of claims 19 to 23, wherein the shaping step includes extrusion of the green material to form a rod.

25. A method according to claim 24, wherein the extrusion step includes forming an axial bore in the rod.

26. A method according to any of claims 19 to 23, wherein the shaping step includes iso-static pressing to form a rod.

27. A method according to claim 19, wherein the shaping step comprises injection moulding the green state material, the injection moulding including forming the recesses.

28. A method according to claim 27, further comprising the step of selecting a mould tool from a plurality of tools of different mould sizes according to the results of a batch testing process used to determine the degree of shrinkage during firing of the green state material, the mould tool being selected to achieve the required core dimensions after firing.

29. A method according to claim 18, wherein the forming step comprises an initial shaping step in which the green state material is formed into a rod, firing the rod into a hard or sintered state, and then machining the rod to form the recesses prior to the metallisation step.

30. A method according to any of claims 14 to 29, wherein the metallisation step comprises coating the core outer surface with a metal colloid and heating the core to form a solid conductive coating.

31. A method according to claim 30, comprising a plurality of alternate such coating and heating steps.

32. A method according to any of claims 14 to 31, wherein the metallisation step includes filling the recesses with conductive material to an extent such that, following the material removing step, the conductive material is flush with the outer surface of the said core portions between the recesses adjacent the recesses.

33. A method according to any of claims 14 to 32, wherein the step of forming the core includes forming the recesses as elongate channels in a configuration corresponding to a required configuration of the antenna element structure.

34. A method according to claim 33, wherein the core is formed as a cylinder and the channels are formed as helices which are coextensive in the axial direction and centred on the axis of the cylinder.

35. A method according to claim 34, wherein the metallisation step comprises filling the channels with conductive material to a depth T, where 0.1W<T<W, W being the width of the channels.

36. A method according to claim 34 or claim 35, wherein the channels are filled with the conductive material to a depth of at least 0.1mm.

37. A method according to any of claims 33 to 36, wherein the core is formed as a cylinder and the recesses include an annular core portion of reduced diameter compared with the diameter of the said body of material between the elongate channels, whereby the metallisation and material removal steps result in a conductive sleeve covering the said annular core portion, and wherein the cylinder has first and second ends, the recesses being formed such that the elongate channels extend from the said first end and the annular core portion extends from the said second end to meet the elongate channels in an intermediate region.

38. A method according to claim 37, wherein the forming step includes forming an axial bore through the cylinder and the metallisation step includes metallising the interior wall of the bore and the said second end of the cylinder to connect the sleeve to the metallised lining of the bore.

39. A method according to claim 38, wherein the forming step includes forming radially extending channels in the said first end of the cylinder and the metallising step

includes introducing conductive material into the radially extending channels to form connecting elements, the outermost ends of the radially extending channels intersecting the elongate channels thereby to connect elongate antenna elements formed in the elongate channels to a feed location at the centre of the said first end.

40. A method according to claim 38 or claim 39, including the further step of introducing a coaxial cable into the bore as a feeder structure, and providing an electrical connection between an outer conductive of the cable and the metallised lining of the bore at least in the vicinity of the said first and second ends.

41. An antenna constructed and arranged substantially as herein described and shown in the drawings.

42. A method of manufacturing an antenna, the method being shown as herein described with reference to the drawings.

The Patent Office

20

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Claims searched:	1 to 42	**Date of search:**	23 January 1997

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Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.O): H1Q (QDJ)

Int Cl (Ed.6): H01Q 1/36, 1/38, 1/40, 9/27, 11/08

Other: Online: WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
Y	GB 2292638 A	(SYMMETRICON) whole document	1, 2, 6, 8
Y	GB 2202380 A	(PHILIPS) see page 3 lines 27-33	1, 6
Y	US 5406693	(EGASHIRA et al) see figure 1	1, 2, 8
Y	US 4862184	(PLOUSSIOS) see column 3 lines 4-18	1,6

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